Framework for Implementing Sustainable Shorelines

Summary of Natural Science Investigations:

Fish, Crab, Shrimp, and Mussels in Marshes

NSF COASTAL SEES Initiative - 2021

Project Activity: Marsh Function Model: Fish and Invertebrate Habitat Provision by Living Shorelines

Objective: Comparatively evaluate fish and invertebrate habitat quality of living shorelines and reference marshes along a continuum of shorescape settings.

Methods: To assess fish and invertebrate habitat use and quality, we randomly sampled 13 pairs of living shorelines (created marsh and stone sill) and reference fringing marshes in areas low, moderate, and high marsh connectivity during summers of 2018 and 2019. Marsh connectivity is defined by the distance to the nearest marsh and presence of barriers to nearshore movement by forage and juvenile nekton, such as deep water and shoreline armoring. Fish sampling was conducted in three habitats of the created and natural marsh ecosystem – shallow water (seine), marsh and marsh edge (fyke net), and marsh surface (minnow trap). Fish condition was determined for two abundant shoreline associated species – mummichog and Atlantic silverside to quantify habitat quality. Fish community measures and other metrics (e.g., nekton diversity, nekton community abundance, nekton community biomass, forage abundance, and juvenile abundance) were derived from fish collections to statistically evaluate marsh habitat function along the continuum of shorescape connectivity.

Marsh invertebrate composition of the marsh and stone sill structure was quantified by surveying 6 transects from low to high marsh (and on the sill if present). To compare invertebrate communities between living shorelines and their natural marsh pairs, we calculated cumulative functional equivalence scores for each living shoreline site based on ribbed mussel, eastern oyster, periwinkle, and burrowing crab densities (individuals per m^2). We are defining a functional equivalence score as the mean value of a given metric at the living shoreline site minus the value at the natural marsh site, divided by their pooled standard deviation. Positive values indicate greater densities at living shorelines, negative values indicate greater densities at natural marshes, and values less than -1 or greater than 1 indicate a sizeable difference between the two site types.

Findings

Nekton: Overall, we found that living shorelines provide similar habitat as reference marshes based on nekton diversity, abundance, and biomass comparisons. In 2018 and 2019, respectively, we collected from 13 paired reference marsh and living shorelines: 22,680 and 20,525 fish; 792 and 1,262 blue crabs; 3,487 and 5,545 shrimp; with a total nekton biomass of 65,084 g and 56,087 g. We captured 37 species in 2018 and 36 species in 2019 resulting in 43 different species across both years. In total, 19 species were considered forage species, and 33 species were comprised of more than 50% juveniles over both years. The most abundant species (comprised 95% of the catch) for both shore types were Mummichog, Shrimp, Silverside, Anchovy species, Blue Crab, Striped Killifish. Generally, species collected were resident marsh species (e.g., mummichog, killifish), forage fish (e.g., anchovy, silverside), and young (e.g., silver perch, spotted seatrout, striped bass, blue crab) and are typical of marsh and nearshore shallow-water habitats that provide refuge and feeding opportunities.


Blue crab


Spotted seatrout - juvenile


Mummichog


Striped Bass - juvenile


Gray Snapper - juvenile

After 2 years since living shoreline construction, we did not detect any trend of nekton habitat use associated with living shoreline age. Juvenile nekton are using living shorelines similarly to natural marshes, while some forage base species (e.g., mummichog) have higher biomass at living shorelines. Among marshes, we found that inundation duration, low marsh, and marsh connectivity explained some of the variation for juvenile species and that inundation duration, low marsh, and bay mouth distance explained some of the variation in forage base species abundance. Marsh connectivity was a poor predictor of forage species abundance but explained juvenile abundance as marshes in more connected regions (low marsh distance) had higher juvenile abundances. Our results indicate that living shorelines are providing suitable marsh habitat for nekton communities, including juveniles and forage base species. The difference in living shoreline construction (rock sill, soil composition) did not appear to diminish habitat quality in the marsh or in nearshore waters, and rock sills may provide enhanced structural shoreline habitat. Living shorelines have the potential to combat marsh habitat loss and provide resilient nekton nursery habitat.

Invertebrates: Overall, invertebrate densities were nearly identical between living shorelines and natural marshes (Figure 1). Across all pairs, none of the mean functional equivalence scores (*Z*) exceeded ±1. There were a few pairs where larger differences were observed (e.g., pair-level *Z*-scores for periwinkles ranged from -2.9 to 1.8), but the overall trend was towards equivalence. The primary difference that we observed was that ribbed mussels were primarily on the rock sill at living shorelines instead of integrated with *S. alterniflora* on the marsh surface like at natural marshes. The separation of mussels and *S. alterniflora* may have implications for nutrient removal and stability/resilience of the living shorelines, but further research is needed.

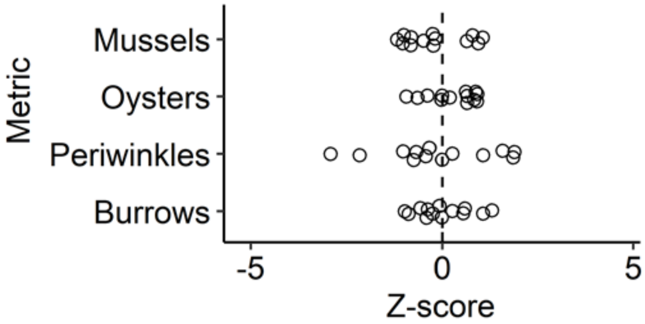


Figure 1 – Functional equivalence (Z) scores for each pair of sites (n = 13) in the survey. *Overall, there was no difference in mean densities for any of the marsh invertebrates that we recorded for this study. The bivalves, though similar in overall density, were predominately on the rock sill at living shorelines.*

Publications

Isdell, R. E., D.M. Bilkovic, A. Guthrie, M.M. Mitchell, R. Chambers, M. Leu, and C. Hershner. **2021**. Living Shorelines Achieve Functional Equivalence to Natural Fringe Marshes across Multiple Ecological Metrics. *PeerJ*.

Guthrie, A.G., D.M. Bilkovic, M.M. Mitchell, R.M. Chambers, J. Thompson, R.E. Isdell. ***In review***. Ecological equivalency of living shorelines and natural marshes for fish and crustacean communities. E*cological Engineering.*

Bilkovic, D.M., R.E. Isdell, D. Stanhope, K.T. Angstadt, K.J. Havens, R.M. Chambers. **2021**. Nursery habitat use by juvenile blue crabs in created and natural fringing marshes. Ecological Engineering 170: 106333. https://doi.org/10.1016/j.ecoleng.2021.106333

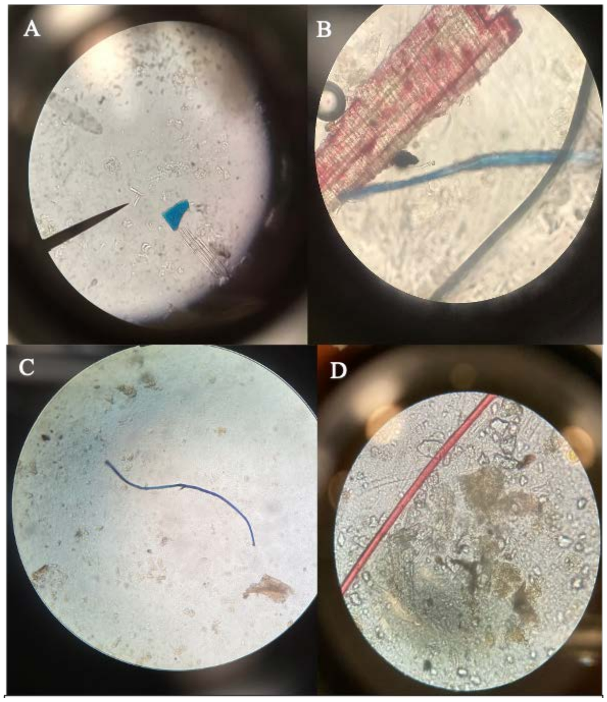
Project Activity: Comparison of Demography and Trophic Ecology of Grass Shrimp *Palaemonetes pugio* from Living Shoreline and Natural Fringing Marshes

Objectives: W&M Biology students Elise Turrietta '19 and Ansley Levine '20 assessed the relative demography and trophic ecology of grass shrimp. They hypothesized that the number, reproductive effort, and diversity of food consumed would be lower for grass shrimp collected from living shoreline marshes relative to natural fringing marshes. They also examined how shrimp populations might be different in relation to living shoreline age and shorescape position (surrounding land use).

Methods: Standardized fyke net collections of shrimp allowed for equal sampling effort from living shoreline and natural fringing marshes. The density of shrimp sampled from fyke nets were compared between marsh types, and subsamples of shrimp were counted for the relative percentages of males, females and gravid females. Egg masses were dissected from gravid females, weighed, and eggs were counted. Egg quality was determined by measuring the weight percent carbon, nitrogen and phosphorus. The cardiac stomachs of up to 20 shrimp from each site were dissected and contents were examined under the microscope. Linear regression was used to examine the relationship between shrimp populations and age of living shorelines. From all 26 living shoreline and natural marsh sites, a multiple regression examined shrimp density in relation to land use area in a 1-km radius surrounding each marsh.

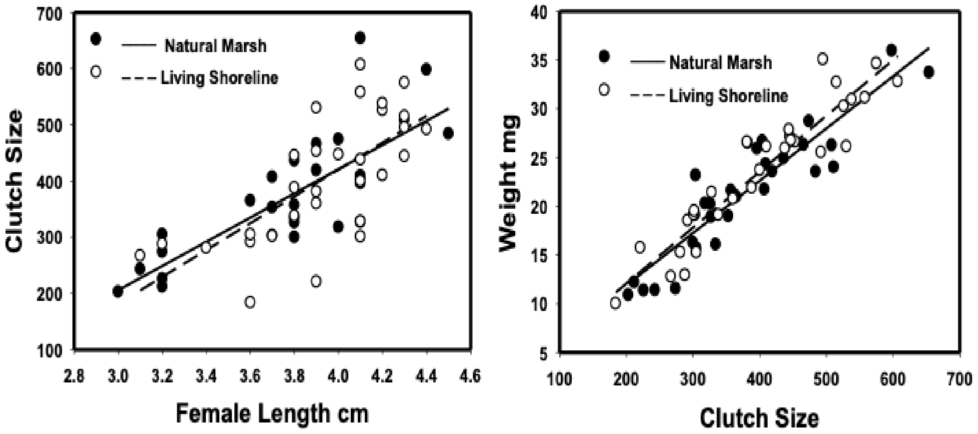
Progress to date: All field sampling and laboratory analysis has been completed.

Visuals:



The common food items identified in shrimp stomachs included invertebrate, algal and plant remains. Also, evidence of microplastic contamination was found in shrimp stomachs from all marshes. Examples of the most common microplastic contaminants identified in Chesapeake Bay shrimp guts (Palaemonetes pugio) from all 22 sites that were sampled. Images are taken at 45x magnification on a standard dissecting microscope. The most frequent plastic gut contents from both restored and natural marshes were (A) bright blue fragments, (B) pink and blue fragments, (C) long blue fibers, and (D) other long colored filaments.

Findings: Between living shoreline and natural fringing marshes, no significant differences were found in shrimp demographics including total density, weight, average shrimp length, number of gravid females, and egg abundance and quality. Gut content analysis demonstrated that diets in general did not differ significantly between marsh types and were dominated by invertebrate, algal and plant (*Spartina*) remains. Overall, shrimp populations differed more among site pairs from different shorescape settings than between created and natural marshes from the same settings, indicating that living shorelines are approaching ecosystem functionality similar to natural marsh habitats. Further, no shrimp metric was positively associated with living shoreline age, indicating that shrimp use of living shorelines was not different 2-16 years post-construction. Among all 26 sites, shrimp density was negatively correlated with the amount of agricultural land use in the surrounding environment, suggesting that some aspect of agricultural runoff (pesticides, nutrients, sediment) might impair shrimp populations.



a) Comparison of clutch size as a function of female length for shrimp collected from living shoreline and natural fringing marshes. b) Comparison of clutch weight as a function of clutch size for shrimp collected from living shoreline and natural fringing marshes. For both comparisons, the slopes of the regression lines were not significantly different.

The observed negative effect of agricultural land use on shrimp density plus the unexpected discovery of microplastics in gut contents from all sites sampled indicate the need for further consideration of human impacts in both constructed and natural coastal habitats.

Product: Levine, A.J, E.M. Turrietta, D.M. Bilkovic and R.M. Chambers. In prep. Demographic and trophic analysis of Grass Shrimp (*Palaemonetes pugio*) from living shoreline and natural tidal marshes in Chesapeake Bay. Northeastern Naturalist.

Project Activity: Marsh Function Model: Ribbed Mussel Habitat Provision by Living Shorelines

Objective: Comparatively evaluate ribbed mussel abundance and habitat quality within living shorelines and reference marshes along a continuum of shorescape settings.

Methods: Field surveys for mussel density from 2018 were paired with spatial and simulated data to establish ribbed mussel distributions and services across both space and time. Settlement pads were placed behind rock sills at living shoreline sites to evaluate whether rock sills fronting living shoreline marshes may interfere with larval mussel access to suitable marsh habitat. A mussel distribution model (MDM) was developed to link shorescape features to mussel density, and was spatially applied to estimate the total abundance and filtration, biodeposition, and denitrification potentials for ribbed mussels in 2018 and 2050. We also compared the functional equivalence of ribbed mussels in living shorelines and natural marshes.

Results: Adult mussels were 4 times more dense in reference marshes (mean ± SE, 82 ± 17 mussels·m^{-2}) than in living shoreline marshes (17 ± 7 mussels·m^{-2}, $t_{(12)}$=-3.544, P=0.004; **Figure 1**). Similarly, juvenile mussels were found in very low densities, when present, in living shoreline marshes (1.1 ± 0.5 mussels·m^{-2}) compared to reference marshes (23.0 ± 6.8 mussels·m^{-2}, $t_{(12)}$=-3.146, P=0.008). Adult mussels appear to be surviving on the fronting rock sill structures at similar densities (86 ± 13 mussels per m^{2}) to those in reference marshes, and juvenile mussels were observed in the highest densities on rock sills (90 ± 11 mussels per m^{2}). Mussel densities Both **marsh type** (β = 1.94, 1.11 - 2.78; mean, 95% credible interval) and **cordgrass density** (β = 0.62, 0.283 - 1.06) had positive, non-zero effects on mussel density, while neither inundation duration (β = -0.22, -0.59 - 0.18) nor distance to nearest marsh (β = -0.15, -0.65 - 0.38) had an effect. Ribbed mussel recruits were observed in settlement pads from all 10 sampled living shoreline marshes. Young mussels were observed even in sites where adults were absent (3 sites) or present in very low densities (< 4 mussels·m^{-2}; 2 sites), indicating that larval mussels are capable of accessing the living shoreline marshes behind the sills.

The living shorelines we surveyed ranged in age from 2 to 16 years and there were significant increases in ribbed mussel density at older, more established marshes, as well as increases with *S. alterniflora* density, although mussel densities were still lower than those in reference marshes. Saltmarsh cordgrass density was similar between living shoreline (163.2 ± 84.4 stems·m^{-2}) and natural marshes (182.3 ± 103.8 stems·m^{-2}), and cordgrass density was not correlated with marsh age; therefore, it cannot be assumed that as a marsh matures, plants will become denser and thereby provide more habitat for ribbed mussels.

Our findings suggest that at most sites larval mussels are able to access and settle on living shoreline created marshes behind rock sill structures, but that most recruits are likely not surviving. Sediment organic matter (OM) and plant density were correlated with mussel abundance, and sediment OM increased with marsh age, suggesting that living shoreline design (e.g., sand fill, planting grids) and lags in ecosystem development (sediment properties) are reducing the survival of the young recruits. To increase recruitment, mussels could be introduced during or after living shoreline construction. For example, live mussels could be allowed to attach to cordgrass plugs from the nursery prior to planting. Constructing the marsh with a seed population of mussels and in a manner that promotes cordgrass density may help accelerate wild mussel recruitment. Throughout the study area, we estimated a 61% loss of ribbed mussels by 2050 (2018: 805 million mussels, 2050: 314 million mussels), and a proportional decrease in water filtration, biodeposition on the surface of the marsh, and denitrification. Living shorelines may help to moderate these losses in developed watersheds where most of the loss was driven by coastal squeeze.

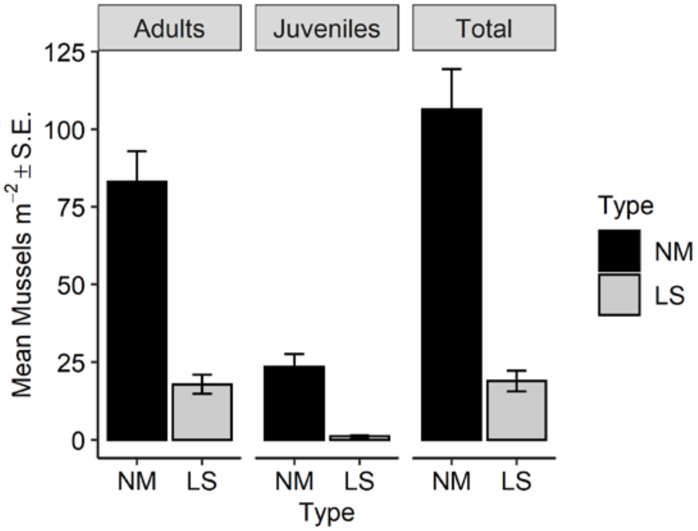
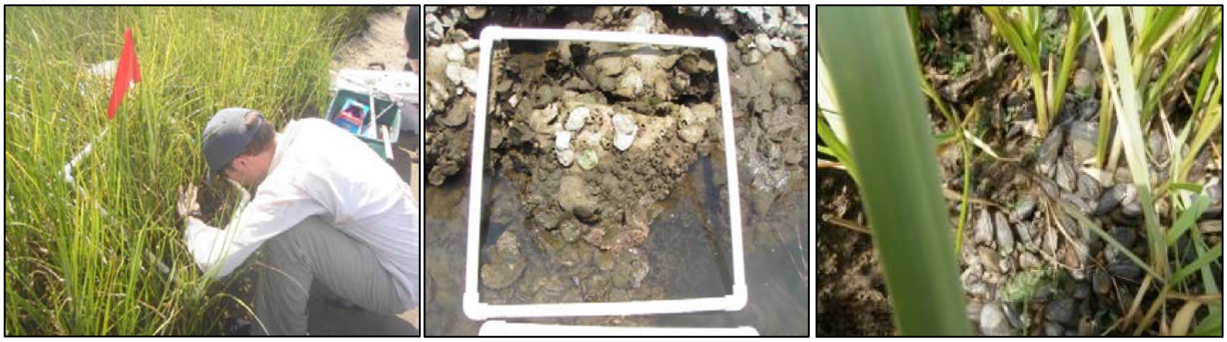


Figure 1. Ribbed mussel abundance in natural fringing marshes (NM) and within the living shoreline marshes (LS).



PUBLICATIONS

Bilkovic, D.M., R. Isdell, A. Guthrie, M. Mitchell. **2021.** Ribbed mussel *Geukensia demissa* population response to living shoreline design and ecosystem development. Ecosphere 12: e03402 https://doi.org/10.1002/ecs2.3402

Isdell, R. E., D.M. Bilkovic, A. Guthrie, M.M. Mitchell, R. Chambers, M. Leu, and C. Hershner. **2021**. Living Shorelines Achieve Functional Equivalence to Natural Fringe Marshes across Multiple Ecological Metrics. *PeerJ*.

Chambers, R, Gorsky, A., Isdell, R., Mitchell, M., Bilkovic, D.M. **2020.** Nutrient Accumulation in Living Shoreline and Natural Fringing Marshes. *Ocean & Coastal Management*, *199*, p.105401. https://doi.org/10.1016/j.ocecoaman.2020.105401

Isdell, R.E., D.M. Bilkovic, C.H. Hershner. **2020.** Large projected population loss of a salt marsh bivalve (*Geukensia demissa*) from sea level rise. *Wetlands*, pp.1-10. https://link.springer.com/article/10.1007/s13157-020-01384-4

Isdell, R.E., Bilkovic, D.M. and Hershner, C., **2018.** Shorescape-level factors drive distribution and condition of a salt marsh facilitator (*Geukensia Demissa*). *Ecosphere*, *9*(10), p.e02449. https://doi.org/10.1002/ecs2.2449